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Introduction

Advantage & Application of ring resonator

• Advantage
  • Compact footprint
  • Low drive-voltage
  • Ability to drive as lumped elements
  • Tunable filters & modulators

• Application for analog optical link
  • Radio over fiber
  • Antenna remoting
  • Subcarrier transmission

Nonlinearity is the key performance metrics in analog optical link.

Modeling of the nonlinearity in the ring resonator

SOLVE
Introduction

Nonlinearity modeling in ring resonator

• Prior modeling

- Plasma dispersion effect in silicon
- Lorentzian-shaped resonance profile
- Cavity photon life time

• Modeling in this letter

Most important source is not wavelength response of ring modulator but PN junction

Minimizing pn junction nonlinearities +
maximizing modulation response and lower optical losses
**Principle**

- **Ring resonator modulator**
  - Constructive interference of light inside the resonator
  - Resulting Lorentzian transfer function
  - For the maximum modulation efficiency
    - Biased at the largest slope of the transfer curve.
    - Introduce nonlinear distortion to the output by curvature

- **Nonlinearity in reverse-biased pn junction**
  - Exhibit a capacitance that is nonlinear as a function of voltage

- **Similar nonlinearity will be seen on the refractive index shift**
  - Voltage vs Capacitance
    - $\approx$ inverse square root
Principle

Nonlinearity problem in ring resonator

- Result of these nonlinearities

- Evaluate the nonlinear distortion performance

Spurious-Free-Dynamic-Range (SFDR):

RF input in the link between the signal level that produces an output equal to the noise level
Design and fabrication

- Cross-section of the waveguide of the ring modulator

- Device layout

- Ring: 30 um radius

- Drop port for spoil the Q

Greater control over modulator’s performance
Larger extinction ratio (ER)
Modeling of ring resonator modulator

1. Refractive index vs. Input voltage

- Voltage vs refractive index

![Electric signal](image)

Carrier depletion effect for shift the resonance in ring resonator is **Not linear**

Analyze by Sentaurus software

Find the relation between refractive index vs input voltage

- Effective refractive index change vs input voltage

![Graph](image)

\[ n_{\text{eff}}(t) = n_\infty + \frac{d n_{\text{eff}}}{dV} \cdot V_{\text{in}}(t) + \frac{d^2 n_{\text{eff}}}{dV^2} \cdot V_{\text{in}}^2(t) + \ldots \]

neff(t) is related to Lorentzian transfer function too.
Modeling of ring resonator modulator

2. Lorentzian transfer function

\[ P_{op}(t) = P_{out,max} \left( 1 - \frac{1}{1 + \frac{4F^2}{\pi^2} \sin^2 \left( \frac{2\pi^2 r \cdot n_{eff}(t) \cdot f_o}{c} \right) } \right) \]

- \( F \): finesse of the ring
- \( r \): radius of the ring
- \( f \): optical frequency of operation

- Not consideration about (low Q, low modulation speed)

Cavity dynamics

Time dependent effect

Free-carrier refraction in the PN junction

3. Detected RF current

\[ I_{RF} = R_{PD} \cdot P_{op} \]

- \( R_{pd} \): responsivity of the photodetector
Analyze the nonlinear distortion

- **Equation for modeling**

\[
\eta_{eq}(t) = n_\infty + \frac{dn_{eq}}{dV} \cdot V_{in}(t) + \frac{d^2n_{eq}}{dV^2} \cdot V_{in}^2(t) + \ldots
\]

\[
P_{cp}(t) = P_{out,\text{max}} \left[ 1 - \frac{1}{1 + \frac{4F^2}{\pi^2} \sin^2 \left( \frac{2\pi^2 \cdot r \cdot n_{eq}(t) \cdot f_c}{c} \right) \right]
\]

\[
I_{RF} = R_{PD} \cdot P_{cp}
\]

IRF can be calculated as a function of time for any input voltage

- **Important impact of this modeling**

Major source of nonlinearity are Lorentizian transfer function & PN junction nonlinearity

**BUT**

By intentionally take out the effect of **PN junction nonlinearity** from model, Performance of SFDR is highly improvement

Majority nonlinearity : PN junction nonlinearity
Result & Conclusion

• Experimental setup

- FSR : 3.2 nm
- Q : 5000
- Tunability : 10.6 pm/V
- Bandwidth : 18 GHz
- Nonlinearity measurement : 1 GHz
- Modulator bias point : Max slope of curve (because of nonlinearity is dictated by nonlinear junction)

• SFDR of the SHD & IMD

\[ \text{SFDR}_{\text{SHD}} = 64.5 \, \text{dB.Hz}^{1/2} \]
\[ \text{SFDR}_{\text{IMD}} = 84 \, \text{dB.Hz}^{2/3} \]

Difference between simulation and measurement : 10 dB
Result & Conclusion

• Conclusion

Analyze about the ring resonator for analog modulation

Non linear refractive index & Lorentzian-shaped transfer function, play a key role in determining the nonlinearity

Important source of nonlinearity is from the PN junction, not a wavelength response of the ring modulator